SEAT BELT INJURIES IN IMPACT

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Abstract

Although the seat belt restraint system has been demonstrated to provide effective reduction of injuries and fatalities in automobile accidents by preventing ejection, with increasing usage of belts by automotive occupants a pattern of injuries directly attributable to impingement on the belt itself is becoming evident. This paper has attempted to bring together the clinical evidence concerning restraint system injuries, discuss gross biomechanical mechanisms of trauma, and evaluate the potential of four principal types of restraint systems in producing injuries. New research findings by the authors are presented comparing the lap belt, diagonal, 3-point, and double torso restraint systems in experimental primate impacts utilizing the 6571st Aeromedical Research Laboratory's Daisy Decelerator, as well as discussion of findings to date related to the effect of the lap belt in impact upon the pregnant female and fetus. The double shoulder harness (with lap belt) appears to offer the greatest protection of the systems compared, while the single diagonal belt (without lap belt) has been demonstrated to be the most dangerous type in certain impact situations. **A seat belt system properly installed and properly worn still offers the single best protection for the automotive occupant during an impact.**

I. Introduction

A number of research and accident investigation studies have demonstrated that the seat belt is the single most effective means of providing occupant protection in a vehicular accident. By preventing ejection, reported to be the leading cause of both injury and death in accidents or in restraining the occupant from being flung about during the impact sequence, belts have been shown to considerably reduce both the severity of injury and fatality (60). The conclusion by Tourin and Garrett in 1960 that seat belts "could save at least 5,000 lives a year and reduce injuries by one-third" (86), has since been supported by similar findings relating to the value of the seat belt by other investigators. Herbert concluded that lap belts reduce injury 35 percent and combined with diagonal belts 80 percent (35); Lister found that seat belts could reduce injuries by 51 percent in Enland (45); and here in Michigan, Huelke and Gikas predicted in their study of fatal accidents that "of 48 ejectees, 38, or 80 percent, would have survived if they had been wearing only the lap seat belt" (37). It is thus somewhat ironic that evidence is mounting that this protective device in itself can be responsible for distinctive injury patterns, one of which was first described as the "seat belt syndrome" by Fish and Wright (19).

The objective of this paper is to present recent clinical and experimental research findings concerning restraint system injuries, briefly compare current systems of restraint as related to the biomechanical mechanism, and suggest ways of reducing the potential of this type of trauma.

Although seat belts have been used for over 50 years in aircraft, they have not had as universal acceptance on the ground. Most of the early seat belt development has been directly in response to aviation and aerospace requirements. Except for special vehicles, it has only been during the past decade that the seat belt has been utilized in the U. S. to any extent. Although a form of lap belt was used earlier in some models of the 1949 Nash reclining seat to retain occupants while sleeping, they were first offered in the U. S. as a safety device in late 1955 by Ford and Chrysler. Since lap belts became stan-

dard in U. S. cars a few years ago, and shoulder or upper-torso restraints (type II) were optional last year, considerably more individuals are wearing belts. Both types will be mandatory in most cars next year. However, it is important to note that an estimated 30 percent, or fewer, of those having belts actually wear them (25, 45, 47).

A 1961 Swedish survey showed, for example, that although 85 percent of all Swedish cars manufactured at that time were equipped with safety belts, two separate investigations showed only 1 out of 4 (25%) motorists using them by 1962 (5). There appears to have been no improvement in usage since then. In a recent series of five surveys of seat belt usage made within the past year by the Ford Motor Company (1966), observers stationed on overpasses above the traffic found that for 779 Detroit expressway motorists utilization of the belt was similar in both weekend and weekday rush hour traffic. While 53 percent of the vehicles observed had seat belts installed, at least one occupant was using them in only 54 percent of these cars. In other words, only one person in a car equipped with belts was using them in only 28 percent of the cases observed (233 of 779 cars). A smaller survey also indicated that for one selected motorist population, seat belts were not used (24% at night, 16% at noon) as frequently for local driving as for Detroit expressway driving (47). Note also that in its *Sixth Annual Seat Belt Installation and Use Survey* (1966) the Auto Industries Highway Safety Committee found "a general downtrend over the years in percentage of use, contrasted with an increase in installation"(4).

If it is true that some 70 percent of vehicle occupants do not use restraints even when available, we may not see drastic improvements until the accident injury and fatality statistics until people are effectively convinced to use them. Nevertheless, due to the overall increase in the wearing of belts, the patterns of injuries which may be identified as caused by the belt are becoming more clear. This makes possible assessments of the protection offered and a need, not previously as evident, to improve the belt systems.

Some idea of the sharp increase in injuries attributed to the seat belt can be found by noting that of the clinical reports referenced in this paper, only three studies occurred prior to 1956, and these were addressed to safety belt injuries in aircraft (14, 83); yet over 20 clinical reports alone have been concerned with this problem

since 1961. This may only reflect the true incidence, since most such cases are probably never reported in the literature.

There currently are four principal configurations of seat belt in automotive use: the lap belt, the single diagonal belt, the three-point (or combination of lap and diagonal), and the double parallel combination of lap and double shoulder harness (Fig. 1). "Lap belt" refers to a single belt across the anterior aspect of the pelvic structure; "seat belt" refers to any combination of lap and torso restraint. There are numerous variations of the types, such as 5-point, double-vertical belts without lap belt, and shoulder belts with inertia reels. Experimental systems now under development and testing for future automobiles will probably use entirely different concepts of restraint. For the purposes of this paper, each of the four systems currently in use will be examined for injury-producing characteristics.[1]

Injuries caused by contact with the instrument panel, steering wheel, or other environmental surfaces will be discussed by other participants of this symposium, and only those injuries which may be directly attributable to the seat belt itself will be included here.

II. Clinical Background

Most cases documented in the literature describe intra-abdominal consequences of seat-belt impact to the soft tissues or neurological, cardiovascular, and endocrine organ systems, although skeletal trauma may also occur.

Teare (1951) found in a 1951 Comet jet airliner crash in England numerous abdominal, as well as thoracic, aortic ruptures which he attributed to the snubbing action of the lap belt with forced flexion of the torso (83).

DuBois reported in a 1952 study, among individuals involved in serious aircraft accidents while wearing lap belts, 23 cases of intraabdominal injuries which could be attributed to the belt, along with 32 cases of contusions along the belt line (15).

DeHaven, Tourin, and Macri (1953) reported an investigation of injuries sustained by 1039 survivors of 670 light aircraft crashes. Except for bruises and minor contusions attributable to safety belts, they found no significant effect due

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[1] Further tests relative to more advanced restraint systems, including both the inverted Y yoke with inertia reel and the airbag system, have been conducted since these data were reported, but too recently to be included in this paper. Preliminary primate impact data on these will be reported at a later date.
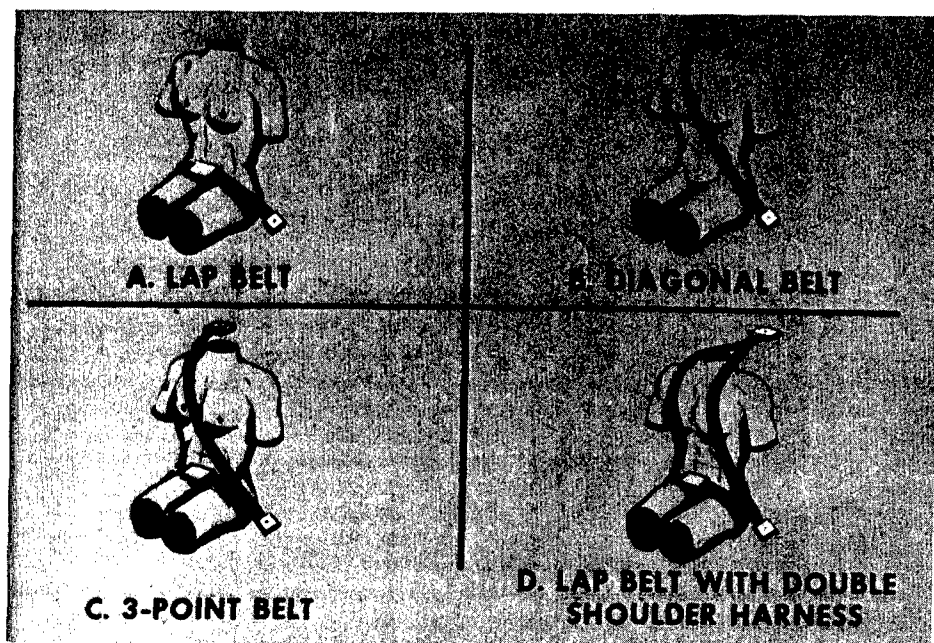
Figure 1. Four basic restraint systems currently used in automotive vehicles.

to severe snubbing action of the belt (14). A more extensive survey by Hasbrook covering 1965 individuals in 913 light aircraft accidents occurring between 1942–1952 confirmed these conclusions (34).

In 1956, Kulowski and Rost reported a case of a small bowel obstruction due to a large adhesion of the terminal ileum to the right iliac crest of the pelvis. Injury to the ileum by the lap belt was proposed as the cause of the adhesions (40).

Garrett and Braunstein (1962) analyzed reports of 944 injured occupants wearing seat belts of which 26 of 150 serious lower torso injuries might be attributable to the belt (26). They found: (1) seven had possible intra-abdominal injuries. One had a ruptured pancreas and duodenum and another had a contused bladder and kidney. Four had abdominal wall contusions from the seat belt. (2) Seven had pelvic injuries of which six were moderate to severe fractures. Of these, two had abdominal wall contusions from the lap seat belt. (3) Twelve had lumbar spine injuries of which eight were serious. One had abdominal wall contusions due to the snubbing action of the belt. (4) Lumbar muscle

sprains or strains were observed in 47 cases, and (5) contusions or soreness over the iliac crests, without apparent internal or skeletal injury, were found in 77 cases.

Cocke and Meyer (1963) reported a severely ruptured spleen as well as left-anterior fractures of the 7th and 8th ribs due to improper looseness and high belt position. They noted that "because of the patient's heavy panniculus," she wore her seat belt loose and high across her abdomen and lower rib cage, "transmitting the impact force to the intraperitoneal organs rather than to the heavy pelvic bones" (12).

Aiken (1963) described a jejunal perforation of the small intestine undetected until the sixth day post-impact. He concluded that the mechanism was sudden compression of the intestine between the seat belt buckle and the vertebral column. The only external indication of seat belt impingement was a "welt" across the lower abdomen, below the umbilicus (1). Tolins (1964) described a severe mid-abdominal wall contusion and a perforation of the upper jejunum to a man wearing a lap belt when his car crashed into a tree (84).

In a questionnaire Tolins (1964) submitted to

19 Naval Hospitals, one lap belt injury resulting in a ruptured sigmoid colon was reported (84).

Intra-abdominal injury occurred more recently to a front-seat passenger wearing a "snug" lap belt when her Volkswagen was struck by an oncoming car. She received a concussion, nasal fracture, and lacerations to the cheek and left elbow. There were numerous contusions and faintly visible marks from the lap belt on the lower abdomen and anterior superior spines. Twelve hours later, surgery revealed a tear of the jejunum about eight inches below the ligament of Treitz, which nearly severed the bowel. The accident occurred about two hours following a large meal and it was noted that the proximal portion of the bowel was well-filled while the distal portion was nearly empty. Disruption occurred at the point where the head of the mass of food had progressed at the time of impact (39).

Gerritsen, Frobese and Pezzi (1966) reported the cases of two nearly identical injuries to two lap-belted, obese women passengers in a head-on collision. Both women were wearing lap belts loosely fastened. One, in the left-rear seat, received a laceration of the jejunum, multiple lacerations of the mesenteric attachments of the small bowel, and traumatic amputation of the lower half of the omentum. The other woman, riding in the right-rear seat, received large laceration of the small bowel, lacerations of the ileum and cecum, with division of the ileocecal artery and a tear of the serosa of the sigmoid colon. These authors theorized that the jerk of the loose belts during impact allowed the lap belt and buckle to go up the abdomen with a shearing force, tearing the "mesentery and bowel along its course, as well as causing contusions of the abdominal wall" (27).

Williams, Lies, and Hale (1966), in observing intra-abdominal injury from lap belts in four cases, note initial symptoms and physical findings may be minimal. External abdominal trauma may conform to the shape of the belts, but absence of such a lesion does not rule out internal injury. Intraperitoneal damage is suggested by increasing abdominal tenderness, gradual loss of bowel sounds, and an otherwise unexplained elevated white cell count. Peritoneal paracentesis may confirm but cannot exclude trauma. Roentgenograms may reveal rupture of the duodenum or gravid uterus. Any abdominal organ may be injured depending upon the position of the belt, and the mechanism may be direct violence, torsion or shearing, entrapment, or a combination of factors. The small bowel and its mesentery appear most vulnerable to direct force, while the body flexion produces a shearing force which may damage the duodenum or pancreas. Perforation of the small bowel or colon may occur as the result of direct violence to a distended loop or entrapment of a short segment to form a closed-loop obstruction, according to their assessment. They also concluded that splenic injury from direct violence occurs only if the belt is improperly applied (89).

Compression fractures to the lumbar vertebra may occur as the individual jackknifes over the lap belt. Garrett and Braunstein (1962) described compression fractures to the lumbar spine in eight cases (26). In one recent case occurring in the Detroit area, a 61-year-old woman passenger in the right-front seat, wearing a snug lap belt, was injured when the car in which she was riding struck another which crossed in front in a left turn. The impact occurred at about 30 mph (?). This individual stated that upon impact she braced herself with her right arm against the instrument panel. Post-impact, she complained of pain in the lower lumbar region, and a compression fracture to the body of the first lumbar vertebra was found.

Howland, Curry, and Buffington (1965) have reported the unique case of a transverse fracture of a vertebral body, which occurred in a 19-year-old youth who ran into a steel pole head-on at an estimated speed of 80 mph. This fracture, discovered one month post-impact, was attributed to high placement of the seat belt, allowing the belt to act as a fulcrum, literally "splitting apart" the vertebral body "similar to breaking a stick over one's knee" (36). A second case has been reported by Fletcher and Bragdon, in which a "splitting" fracture of the pedicles, transverse processes, and lamina of the third lumbar vertebra occurred in a (loosened) lap belted 21-year-old female who struck a semi-tractor truck in a sports car at a high rate of speed (21). Kaufer and Smith, at the University of Michigan, have found ten cases apparently involving a tension type mechanism previously not described (63).

It should be noted that Nahum and Siegel, in their unpublished study of over 150 accidents in the Los Angeles area, have at present over 30 cases of seat belt injuries (53).

Seat Belt Injuries to Pregnant Women. Although traumatic rupture of the pregnant uterus

through external force has been reported in accidents in which seat belts were not worn (17, 92), injuries to pregnant women due to the seat belt have only been recently reported. Rubovits (1964) first reported the traumatic rupture of a six-months pregnant uterus in a woman whose car was struck at 35 mph by another vehicle head-on front quarter, when the other vehicle jumped a divider. There was avulsion of the uterine musculature at the site of the seat belt impact. This was attributed to the force of the belt at the anterior uterine wall being transmitted to the fetus, "which was then blasted through the left uterine wall" (58). This was fatal to the fetus. As in the case reported above, absence of sign of shock or intraperitoneal hemorrhage precluded diagnosis for two days.

Hurwitt and Silver (1965) reported the case of a woman developing ventral hernia seven month's post-impact "presumably caused by the snubbing action of the seat belt during the accident" which occurred at an estimated speed of 60-70 mph into an abutment. She also received fractured transverse processes and subluxation of the fourth lumbar vertebra over the fifth (38).

Fish and Wright (1965) noted two cases of rupture of the pregnant uterus caused by seat (lap) belts reported to them by Dyer (19).

The remark of one physician relating to an impacted patient, that "there is no question that the seat belt cost the life of the fetus, but there is also *no question* that it saved the mother's life," seems to sum up both the clinical evidence to date and the experimental research which we have conducted concerning impact to pregnant females. Out of 30 cases of accidents involving pregnant women wearing seat belts which one of us (W. M. Crosby) has collected, death to the fetus occurred in 12 cases (or nearly 50 percent, since 11 have not yet delivered), even though the mother survived. As will be shown, results of our experimental tests on pregnant baboons have approximated this experience, with resultant death to the fetus at all levels from 20–40 G, even when the mother would have survived.

Cases which have come to our attention to date are tabulated briefly in Table I, although some are not yet completed (13). Two-thirds of these women were riding in the right-front seat, and the balance were driving the vehicle (except for one woman 2 months pregnant involved in an aircraft accident who was riding in the rear of a tandem seat) (65). Ages ranged from 19 to 30 years, and term of pregnancy from 6 weeks to 40 weeks. Of these 30 cases, 24 were forward-facing in impact orientation, five were rear-ended, thus rearward-facing to the impact, and one, hit broadside, was lateral to the impact force. None of the rearward-facing impacts caused more than contusions, although two claimed symptoms of hyper-extension/flexion (or "whiplash") to the neck.

Most of the cases involved lap restraint, but unfortunately, belt position and snugness were not known for most of these. In one case, a woman (40 weeks pregnant) was subjected to an extreme bump (vertical force) when the car in which she was riding hit a deep hole in the road. She had placed the belt *over* the fundus, and the jolt apparently caused placental separation and a premature, but normal, birth. In a second case in which the lap belt was placed *over* the fundus in a woman 36 weeks pregnant, the injuries in the subsequent accident were fatal to the fetus, causing a deep laceration on the posterior aspect of the uterus and extensive belt contusions. In these cases, the high placement of the belt probably contributed to the injuries.

In view of the additional protection claimed by proponents of the diagonal restraint system, it is of interest that two cases of extensive injuries to the mother have occurred in accidents utilizing this restraint. In one instance, the woman was a right-front seat passenger in a small foreign car which had a head-on collision with a larger one. Impingement of the diagonal seat belt caused fractures of every rib on her left side, rupturing her spleen and causing massive intra-abdominal hemorrhage. Post-impact, an outline of the belt (in ecchymoses) was visible extending from right shoulder to left thigh. The fetus was stillborn 48 hours post-impact. The diagonal belt did not prevent both her head and knees from impacting the panel.

Injuries to the chest and head of a pregnant woman also occurred in a second case, under almost identical conditions; however, the outcome of trauma to the fetus is still unknown.

Although we have found only 30 accident cases thus far, the trend of abdominal impingement by seat belts in accidents may be expected to occur more often as more belts are worn. Approximately half of the clinical cases collected to date involve a partial or complete separation of the placenta with subsequent death of the fetus.

TABLE I. SEAT BELT IMPACT INJURIES TO PREGNANT WOMEN

Type/Accident	Seat Position (1)	Type/Restraint	Belt Fit	Age	Preg. Term	Injuries Maternal (2)	Fetal
FORWARD FACING IMPACT							
1. Head-On Auto	RF	Lap	-	20	26	1	FATAL (+1 hr; Stillborn 30 hrs)
2. Auto, Hole/Road	RF	Lap	Over Fundus	22	40	0	None (premature; placental sep?)
3. Auto,	-	Lap	-	26	34	1 (weeks)	FATAL (Still. + 12 hrs)
4. Auto,	-	Lap	Over Fundus	26	36	1, 2	FATAL (Still. placental sep.)
5. Auto, 30 mph into tree	Driver	Lap	-	21	32	0	None
6. Head-On Auto	Driver	Lap	-	32	14	1	None
7. Auto, 20 mph by 60 mph	RF	Lap	-	-	12	1	None
8. Auto,	RF	Lap	-	-	33	0	FATAL (+8-10 hrs; Still. 10 days)
9. Auto,	RF	Lap	Loose	-	24	1	Not yet delivered
10. Auto,	RF?	Lap	-	20	20	1	FATAL (Still, 14 days)
11. Auto,	RF?	Lap	-	-	19	1	FATAL (Still, Caes. 3 mo.)
12. Auto, 35 mph hit 25 mph	RF	Lap	-	23	-	1, 2	FATAL (Uterus ruptured)
13. Auto, Side into ditch	RF	Lap	-	31	6	1, 2	None (Birth + 7-1/2 mos.)
14. Head-On Auto	RF	Lap	-	28	28	1	FATAL (Still., Intracranial Trauma)
15. Head-On Auto 20-25 mph	Driver	Lap	Over Hvy Coat	29	16	1	None(?) Not yet delivered
16. Auto, into rear of 2nd car	RF	Lap	Loose	29	16	0 (Head)	None(?) Not yet delivered
17. Auto, rolled left side	RF	Lap	-	19	32	0(?)	None(?) Not yet delivered
18. Auto,	-	Lap	-	-	18	1	None(?) Not yet delivered
19. Auto,	-	Lap?	-	-	36	1, 2	FATAL (Stillborn 6 hrs)
20. Auto, 35 mph	RF	Lap?	-	-	24	1, 2	FATAL (Uterine rupture)
21. Auto,	-	Lap?	-	-	12	1, 2?	None(?) Not yet delivered
22. Aircraft, spin/crash	Tandem rr. seat	Lap	-	26?	8		None (Normal delivery + 7 mos.)
23. Head-on Auto	RF	Diag Only	-	30	22	1, 2	FATAL (Still, 48 hrs)
24. Auto, Skid	RF?	Diag Only	-	22	-	1, 2	None(?) Not yet delivered
REARWARD FACING IMPACT							
25. Auto, hit from rear	Driver	Lap	Snug	34	30	0	None
26. Auto, hit from rear	RF	Lap	-	20	28	1	None(?) Not yet delivered
27. Auto, hit from rear	RF	Lap	-	31	16	0(pain nk, bk)	None(?) Not yet delivered
28. Auto, hit from rear, 3-car	RF	Lap	-	28	28	0(pain neck)	None(?) Not yet delivered
29. Auto, hit from rear	Driver	Lap	-	19	24	1?	None(?) Not yet delivered
SIDE FACING IMPACT							
30. Auto, hit broadside	Driver	Lap	-	-	16	0	None. Normal delivery

(1)RF = Right Front
(2)Maternal Injuries: 0 = None, 1 = Contusions, 2 = More Serious Trauma

III. Experimental Data

At the 10th Stapp Car Crash Conference in November, 1966, we reported the preliminary results of the first experimental approach to impact injury to the pregnant female (66). Although this study will not be concluded until June, 1967 (13), a total of 11 of the 15 scheduled tests have been run.

This study was initiated as a joint effort of the Federal Aviation Agency, USAF 6571st Aeromedical Research Laboratory, the University of Oklahoma School of Medicine, and more

recently by the Southwest Foundation for Medical Research, at the request of the Air Line Pilots Association and the SAE S-9 committee, to determine the effects of abrupt deceleration on the mother and her fetus when restrained by a lap belt. It was calculated that the crash landing of a jet transport, losing one engine immediately after takeoff, at full gross load, could impose resultant forces of 40 G at 45° (-G$_x$) upon a woman seated in the forward section. This was the most extreme crash condition estimated to be survivable, and formed an intial basis for the first test. This was not found to be survivable for the lap-belted baboon subject, so the remainder of the forward-facing tests were run at 20 G deceleration patterns.

For these tests the Daisy decelerator at the 6571st Aeromedical Research Laboratory at Holloman Air Force Base, New Mexico, was utilized, with female adult Savannah Baboons (*Papio cynocephalus*)[2] as experimental subjects. This primate has a uterus simplex and a gestation period of 180 days.

A seat, scaled to fit the baboon, was oriented in the 45° forward-facing body orientation (aircraft) for the first 7 tests, and at 0° (automobile) for the remaining 7 tests. (One test was a sham, with the animal undergoing all preparation and instrumentation, but no impact run conducted.) A 2 inch Ensolite seat cushion was added to prevent artifactual iliac fracture. Impact restraint consisted of a 1 inch 4500-lb test nylon webbing belt adjusted statically on the seated animal to 1.5 kg. by tensiometer. The belt angle was adjusted to 55°, and strain gages were mounted on each side of the lap belt. Initial animals were restrained for handling by modified upper torso jackets, but these were found unnecessary in subsequent runs.

Physiologic monitoring of intrauterine pressure, maternal EKG, fetal EKG (four animals), maternal blood pressure, and intra-abdominal pressure (1 animal), were recorded with an 8-channel Sanborn and Ampex CF-100 tape recorder. In addition, tracings of the seat-belt tensions and G-profile were recorded by CEC recorder. Photographic documentation included lateral and overhead 16-mm high-speed (2000 fps) motion pictures, still coverage, and 35-mm color photographs of gross and microscopic trau-

ma. In subsequent tests a 1000 fps, 35-mm photometric camera was also used. A Field Emission Fexitron Flash X-ray System was triggered at impact and at various time intervals ranging about 0.065 seconds after entrance of the sled into the water brake, to study body organ displacement at impact. Post-run whole body x-rays were taken on each animal. Forces on the left and right lap belt were measured in all forward-facing impacts, and on the shoulder belt in the two rearward-facing impacts, where a 3-point type of harness was utilized.

In the 45° seat pitch attitude it was found that (a) during acceleration the abdomen is tensed, raising the intrauterine pressure prior to impact; (b) at approximately 0.050 seconds after the onset of deceleration the animal is pressed down into the seat causing a rise in intrauterine pressure *before* "jack-knifing" begins; (c) following the initial positive peak, the intrauterine pressure drops sharply at about 0.100 seconds, and then rebounds to a second, positive peak, averaging about 400 mm Hg at about 0.170 seconds. This second peak is attributed to the sudden impingement of the uterus between the belt and the spine when the animal is fully flexed anteriorly. In one test, in which the animal was restrained by a double shoulder harness system, there was an absence of the second intrauterine pressure peak. However, the maximum uterine pressure was 500 mm Hg or very similar to that found in the animals restrained by lap belt alone despite the fact that the forces on the seat belt were very much lower. This indicates that for the gravid uterus, at least, increases in intrauterine pressures can be expected even when the body is totally restrained from forward flexion.

Additional findings have included the presence of post-impact bradycardia in both fetus and mother. In one case, during surgical implantation of transducers the animal expired during anesthesia. This animal, fully instrumented, was nevertheless run as scheduled at 33 G, forward-facing, lap-belt restrained. This was the first cadaver control to be run on the Daisy track, and it is of interest to note that the intrauterine pressures corresponded closely to those found in the living animal.

Three fetal deaths occurred 1-1/2 hours post-impact in the 20 G forward-facing orientations. Two subsequent runs in the rearward-facing position, considered to provide the best protective support, have resulted in fetal demise immediately post-impact at 40 G, and fetal demise

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[2]At the beginning of these studies, this animal was designated *Papio doguera*, but has since been assigned the new taxonomic name *Papio cynocephalus*. It is known as the Savannah baboon, rather than Kenya baboon.

within 24 hours post-impact at 20 G. Although these forces are well below human injury tolerance levels for these body orientations, in both of these there was no maternal trauma. Initially, maternal neurogenic shock appeared to be the most likely cause of death. However, to date only two fetal deaths remain unexplained; death in the others being attributed to fetal skull fracture, cerebral hemorrhage, or placental separation. Hopefully, such experiments may lead to an explanation for similar unexplained fetal deaths occurring in humans in automobile accidents. As noted in Table I, 50% of the forward-facing impacts in actual automobile accident cases involving pregnant women which have come to our attention have resulted in fatality to the fetus, despite the lack of observable trauma in most instances. Placental separation, an expected finding, occurred in only two of the tests to date. It should be emphasized that we feel the lap belt, properly worn low over the abdomen, nonetheless affords considerably more protection to any pregnant occupant than no restraint at all.

IV. Injury Comparison of Belt Systems

A total of 45 baboon tests have been run under controlled conditions and are summarized in Table II. A major purpose of these tests has been to experimentally determine the relationship between body and seat orientation, force patterns, and the effect of various restraint configurations upon whole body injury tolerances.

Several investigators have found intra-abdominal injuries (12, 27, 29, 89) believed to be related to loose, improperly worn lap belts. In an effort to reproduce injuries found clinically which might be attributed to the shearing force (between lap belt and spine, for example) (1) several subjects were impacted with the lap belt purposely positioned high and loose. To avoid surgical artifacts, no physiological instrumentation was done on any but the pregnant series. Animals were sacrificed post-impact and gross and microscopic necropsy accomplished.

Two forward-facing impacts have been run at 34.2 G and 30 G. At 30 G the impact, even with the lap belt worn loosely and positioned high on the abdomen, produced no significant trauma. The animal, terminated post-run, was found at necropsy to have a belt contusion with subcutaneous hemorrhage, hemorrhage at the head of the pancreas, bilateral hemorrhage of the kidney

pelvis, and uterine subserosal congestion. At 34.2 G the impact was fatal, mainly due to the rupture of a major neck vessel. There was also moderate hemorrhage of the anterior bladder, bilateral perirenal hemorrhage, avulsion of the abdominal muscles at the pubis, severe transverse lacerations (artifact) of the buttocks, contusion and subserosal hemorrhage of the neck of the uterus. The lap belt caused a severe transverse contusion 3 cm wide across the lower abdomen. In each case the lap belt restrained the animal in the seat. This is particularly noteworthy because the baboon has a slightly higher center of gravity than the human, and thus may be expected to flex even more than the human.

In one 31 G impact in the 90° left lateral position, the loose high position of the belt resulted in a ruptured uterus, peritoneal tear of the proximal rectum, and slight areas of hemorrhage in the right axilla and superior to the pubis.

Several investigators have described accidents in which injuries were ascribed to the occupants' wearing the single diagonal belt incorrectly, under both arms. However, as was indicated in the clinical background, and as will be further noted in the discussion section of this paper, injuries of the thorax are particularly prevalent in impacts involving wearers of the diagonal belt. To compare the protective qualities and possible injury patterns of various belt systems, the diagonal belt has been utilized in three tests, two forward-facing and one 90° lateral, all at identical 30 G deceleration patterns. Because of the apparent extensive trauma incurred by baboon subjects wearing this belt system in comparison to that occurring with the other systems studied, a further series is planned to include impacts in both left and right 45° and 90° lateral impacts, as well as low level forward impacts.

In each case the subject was not restrained by the belt, and was flung from the seat, literally hanging himself as rotation occurred about the inferior axis of the belt, as seen in single-frame high-speed photographic analysis. In one forward impact the rotation caused the lower portion of the body to pitch up about the belt so that at one point in the impact sequence the body was horizontal in the seat, then rotated so that the head was on the seat with the feet straight up in the air vertically, finally coming to rest outside the belt at the foot of the seat. Since this system does not use a lap belt, the lower body is free to swing violently forward with a torquing motion.

All three impacts with diagonal belts only

195

TABLE II   SUMMARY OF IMPACT TESTS

Test No.	Daisy Run	Restraint System	Special Condition	Body Orientation Relative to Force Direction	Seat Pan** Orientation (Pitch)	Peak G	S L E D Entrance Vel. (ft/sec)	Onset Rate (g/sec)	Time Duration Plateau	Total
1	3315	Lap Belt	Loose/High Dead Preg.	Forward (-G_X)	20°	34.2	77.7	6800	.055	.075
2	3317	"		"	"	33.0	74.3	5500	.057	.085
3	3125	"		"	"	31.0	74.4	3100	.056	.091
4	3126	"		"	"	30.7	74.2	3100	.046	.091
5	3372	"	Loose/High	"	"	39.0	74.2	3000	.055	.094
6	3311	"		"	"	22.0	61.3	3300	.075	.110
7	3035	"		"	"	22.0	51.0	2000	.053	.059
8	3313	"	Pregnant	"	"	21.8	61.0	2000	.075	.102
9	3036	"		"	"	16.5	38.2	1500	.056	.094
10	3020	"		90° Left Side (-G_y)	"	44.0	87.1	4700	.044	.080
11	3122	"		"	"	31.0	74.6	3100	.053	.097
12	3123	"		"	"	30.0	74.8	2600	.053	.096
13	3369	"	Loose/High	"	"	31.0	74.8	3100	.055	.093
14	3022	"		"	"	30.5	73.6	3100	.055	.094
15	3023	"		"	"	30.0	75.0	3000	.056	.096
16	3034	"		"	"	28.7	72.9	2700	.057	.093
17	3031	"		"	"	27.8	62.0	2200	.050	.094
18	3030	"		"	"	27.5	62.1	2100	.048	.091
19	3128	"		"	"	26.4	60.9	1200	.045	.100
20	3033	"		"	"	26.0	60.5	1500	.030	.094
21	3025	"		"	"	26.0	50.7	2400	.054	.091
22	3120	"		"	"	23.0	60.4	2600	.063	.100
23	3018	"		"	"	23.0	58.4	2200	.066	.083
24	3015	"		"	"	20.0	57.3	2100	.067	.095
25	3025	"		"	"	20.0	38.3	1400	.050	.091
26	3027	"		"	"	16.5	36.4	1200	.055	.098
27	3134	"		"	"	44.0	88.2	5900	.017	.076
28	3133	"		"	"	31.5	74.1	2600	.034	.095
29	3132	"		"	"	31.0	59.1	2300	.051	.088
30	3131	"		"	"	22.0	39.9	3000	.065	.100
31	3316	Diagonal	Forward	Forward-Facing	"	30.0	75.8	4000	-	-
32	3371	"		"	"	30.0	74.7	3000	.054	.093
33	3368	3-Point		90° Left Side	"	30.0	74.6	3000	.055	.091
34	3370	"		Forward-Facing	"	30.0	74.2	3000	.057	.093
35	3314	"		"	"	22.2	61.2	2000	.072	.098
36	3367	"	Pregnant	90° Left Side	"	30.0	74.5	3000	.054	.093
37	3364	"	Pregnant	Rearward (-G_X)	"	30.4	84.4	5400	.050	.077
38	3365	Full Force Lap Belt		"	"	20.2	60.0	2500	.074	.108
39	3310	"		"	"	20.5	60.4	2700	.073	.115
40	2890	"		Forward Facing	45°	40.0	87.0	4000	.080	-
41	2882	Lap Belt	Art/Uter.	"	"	20.0	63.1	1500	.080	-
42	2885	"	Art/Uter.	"	"	20.0	63.3	2000	.080	-
43	2886	Full Torso	Art/Uter.	"	"	20.0	63.3	2000	.080	-
44	2888	Lap Belt	Pregnant	"	"	20.0	60.3	2000	.090	-
45	3-62	"	Pregnant	"	"	26.0	60.3	2000	.080	-

* Does not include three sham control animals.
** Seat back seat-pan (SRP) angle is 90°.

were instantly fatal to the subject. Injuries were similar in each case, with a high proportion of rib fractures and thoracic injury caused by impingement upon the diagonal belt. In the 90° left lateral impact (diagonal over left shoulder as in driver position), necropsy showed the following trauma: complete avulsion, right pectoral muscle; severe intramuscular hemorrhage, left pectoral muscle; comminuted fractures, all ribs left side 2-6; entire right chest wall presents massive destruction with extensive hemorrhage; hemorrhage of the intercostal muscles, left 1-3 ribs; ecchymotic hemorrhage of the pericardium; laceration of apical lobe, right lung; anterior mediastinal hemorrhage; hemorrhage of hylus of liver; extensive bruising right axilla; pericapsular hemorrhage, right adrenal; five hemorrhages of spleen; and rupture of wall of the left ventricle of the heart. Similar injuries, incuding rupture of the spleen, fractures of 8-10 left ribs, lacerations of the liver, ruptures of the sigmoid colon, and hemorrhages to the pancreas, adrenals, kidneys, and stomach, were found in the forward-facing impacts with a diagonal belt. Too few tests have been run to be conclusive, but as will be noted, even the loose, incorrectly placed lap belt did not produce the extent of trauma observed in the single diagonal belt restraint impacts under identical force conditions, either in the forward-facing or 90° left side impact.

One run at 20 G utilizing a double shoulder harness produced no injury to the animal. Further runs at higher levels were not made because extensive tests have been made of this configuration in animal tests by other investigators.

Five decelerations from 40.4 to 22 G have been made utilizing the 3-point restraint (Type II) system, including rear-facing, forward-facing, and one 90° left lateral impact. No trauma, other than minor external belt contusions, was found in either the 22 G or 30 G forward-facing impact. No trauma was found in either the 40 G or 30 G rearward-facing impacts. This system appeared to offer much better protection than either the diagonal or lap belt only. However, since it appeared that in a left side impact a driver wearing a 3-point system could receive serious neck injuries, one 30 G run was made in this body orientation. In this case, findings included extensive areas of subpleural hemorrhage involving the right chest wall from ribs 2-7 and from ribs 3-6 and 11-13 on the left side, along with large contusions of the shoulder due to the belt. The most disturbing finding was a total dislocation of the occipital-atlantoid joint, accompanied by intramuscular hemorrhage extending from the first to 6th cervical area of the neck. Impingement of the neck upon the belt was sufficient to cause death in this left 30 G lateral impact. To determine further effects of lateral impacts with the 3-point (Type II) system, additional tests involving left and right 90° and 45° lateral impacts will be conducted. Figure 2 provides a relative comparison of belt loads in baboon subjects at 30 G impact with four restraint systems.

As noted in Table II a number of lateral tests have also been run utilizing lap belt restraint only. These were reported 10 April at the Aerospace Medical Association meeting in Washington, and will be published in *Aerospace Medicine* (67). An unexpected finding in these tests was the significant pancreatic hemorrhage occurring in lateral impacts as low as 16.5 G. Previous human tests had reached a subjective tolerance limit at only 9 G (97). This trauma was determined to be due to impact impingement from the lap belt rather than post-mortem autolysis.

To our knowledge such trauma has not previously been described, and the significance of the interacinar and intralobular hemorrhages observed in the pancreas should merit further study of the effect upon survivability.

Search of the literature has revealed descriptions of pancreatic trauma related to dietary excesses, direct trauma resulting from blows over the left upper quadrant of the abdomen, surgical trauma, and reflux from the intestine. However, we have found no reports of pancreatic injury associated with violent compression and/or displacement of the viscera such as that found in this series of experiments. Retroperitoneal and intralobular hemorrhage was observed immediately after impact in gross necropsy, and upon histological examination interacinal hemorrhage was also found. Although it must remain speculative until further clinical study of survivors is done, we feel that intra-abdominal forces were sufficient not only to rupture the capillary bed but also to break the more delicate radicles of the intralobular ducts which are formed only by the centro-acinous cells with the release and activation of pancreatic enzymes.

While this continuing series of impact tests, considering variables such as restraint system, direction and magnitude of force, body orienta-
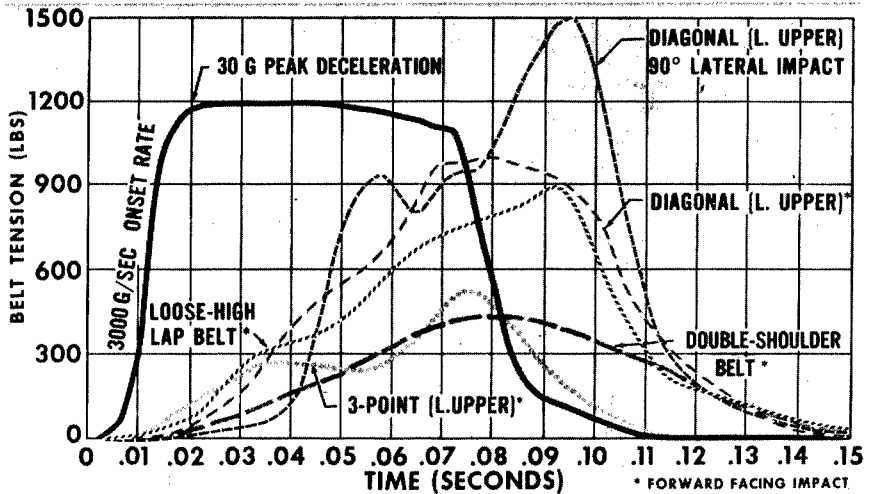
Figure 2. Comparison of belt loads in baboon subjects 30 G impact with four restraint systems.

tion, time duration, seat pitch, and other factors, may not appear extensive, it must be pointed out that to our knowledge, these represent the first experiments conducted utilizing living subjects, involving the 3-point harness and the pregnant female and fetus, and the first lateral tests of the lap belt at levels above subjective human tolerances.

V. Gross Biomechanical Considerations

The kinematic action of the body during belted impact has been well documented by analysis of high-speed cinephotography during impacts of anthropomorphic dummies (24; 28; 55; 61; 62; 81; 94; and many others). McHenry (1965) has attempted to analyze the dynamics of the lap belt or combination of lap belt and shoulder restraint through a seven-degree-of-freedom nonlinear mathematical model of a human body (48). The dynamics of belted, specially "flexed" human cadavers have been studied by Patrick and Daniel (54). Researchers utilizing the Daisy Track at Holloman Air Force Base, New Mexico, have utilized high-speed photo analysis of both animal and human subjects (69–79; 82; 97) as well as photometric computer analysis of motion during impact (68).

Each of these techniques for understanding the biomechanics of injury and restraint during impact has shortcomings which persist in preventing us from learning as much as we need to

know to design for optimum occupant safety. Anthropomorphic dummies are most commonly used for testing where human simulation is necessary but where it is much too dangerous to use human volunteers; however, dummies are also the most misused and least understood device utilized. All too often the anthropomorphic dummy, which can be an excellent engineering tool for determining such things as amount of force and duration of force, becomes to the engineer an accurate human simulator, which it is in only very limited ways. It is indeed a risky business to attribute, as has been done, specific trauma to a dummy impacted in a crash. Accelerometers attached to the nonyielding steel framework of the dummy cannot be quantified to damage to soft tissue, organs or to the cardiovascular, endocrine, or neurological systems. What are the internal pressures, the distortion of the heart and other organs? Thus an impact quite tolerable by dummy standards may not be for the actual human. Similarly most dummies as actually used in tests today are based upon physical dimensions derived from a specific young, male, physically select military population, and do not necessarily represent the range of automotive vehicle occupants in physical size or attributes. Even the most valid attributes of the anthropomorphic dummy, the range of joint movement or centers of gravity, may be questioned since much of the basic data were derived

from only three elderly (67–71 years) male ca-
davers. More recent data upon 14 cadavers
ranging in age from 21 to 67 years has not as
yet been published (95). The variation of tight-
ness of joint movement (force) does allow repro-
ducible standardized testing, which is, of course,
the function of the dummy, but at the same time
this may not be accurate enough. In a recent
study each of 23 anthropomorphic dummies used
in one organization's test operations was care-
fully measured and examined for conformity to
the manufacturer's basic design specifications.
It was found that in dummies procured exactly
the same for the 50th percentile size, for exam-
ple, body weight varied by 12 pounds and total
height by 2.6 inches (96). Obviously some dum-
my users are not aware of this quality control
variable in their tests, since most users do not
have sufficient numbers of means to check their
dummies. Nevertheless, the anthropomorphic
dummy, despite its limitations, offers a valuable
testing device where humans cannot be used and
where the results are not extrapolated too far.

Mathematical models of the human body are
an interesting approach and may be of great use-
fulness to the design engineer in testing restraint
systems under various known conditions. The
models by von Gierke and his associates have
made large contributions to our knowledge of
human responses in simulated vibration and im-
pact environments (88). However the limiting
factor in such use is that the mathematical sys-
tem can be no more valid than the biological in-
puts, and present knowledge of the biological
mechanisms of impact is much less comprehen-
sive than engineering and mathematical technol-
ogy. Human body simulation in this area is
complicated by the fact that the human body is
of nonlinear, heterogeneous visco-elastic compo-
sition which still defies precise mathematical
quantification, and human variability cannot be
overemphasized.

Animal testing, particularly of primates simi-
lar to man, is one approach which may provide
valid data based upon biological response in a
living organism. But there are also many prob-
lems here. Extrapolation of data to the human
cannot always be validated. Structural differ-
ences such as differing numbers of vertebra, lack
of lumbar curve, position of the foramen mag-
num (affecting CG of the head), or even addi-
tional muscles not found in the human, can affect
results. Physiological variances in the cardiovas-
cular, neurological, or endocrine systems can

play a part. The animal researcher in impact can
seldom test all variables, and such considerations
as the effect of anesthesia upon response are
often valid questions. Although considerable ad-
vances in micro-instrumentation and measure-
ment have been made, these often in turn present
questions of artifact, e.g., how much effect upon
the results of the experiment did the surgical
procedure have? Yet, outside of the human volun-
teer, the closest material the physiologist can
work with is the living, functional biological
system of the non-human primate.

Human cadavers have been experimentally
used in impact in limited experiments but are
subject to many of the uncertainties of other
methods. To be at all realistic the body must be
either fresh or artificially manipulated, since
muscle tonus can be an important factor. Since
it is not a functioning biological system, discrete
trauma to body organs and soft tissues can only
be inferred. Problems of availability, limited se-
lection (usually old, small, infirm, and with
quite changed body fluids and tissues), security,
and preparation plague the researcher utilizing
cadaver subjects. Furthermore, research in pro-
gress by Life and Pince comparing living versus
embalmed tissues has already demonstrated that
there is a considerable difference in skeletal tis-
sue reaction to impact, with embalmed cadaver
skulls, for example, "shattering" while living
tissue under identical force conditions may not
even fracture (43).

Use of human subjects also has extreme limi-
tations for the study of body kinematics in im-
pact as well as impact trauma, since human
volunteers can not go above the subjective non-
injury (reversible injury) impact level, so this re-
alistic exploration of biomechanics is somewhat
restricted.

As a result of these and other problems (see
Severy, 1965, for further discussion) of valid
human simulation, many researchers utilize a
combination of techniques to extrapolate data
to obtain meaningful valid information. Care-
fully controlled experiments using anthropomor-
phic dummies, cadavers, primates, and humans
under identical impact conditions could do much
to resolve some of the problems brought out
above. Several attempts at this have been made.
In an unpublished 1964 study Patrick and Daniel
compared the kinematics of the anthropomorphic
dummy, the flexed human cadaver, and the liv-
ing human volunteer with lap belt restraint in
impact. However, due to pain, welts over the

199

thighs, and lumbo-dorsal strain, the human run had to be subjectively terminated at 12.9 G. They concluded that at relatively low impacts the kinematics were similar (54). But such may not be the case at higher levels commonly encountered in accidents. In two primate impact tests the authors conducted at 30 G and 40 G the impacts were so much more violent (lap belt only) than at 20 and 25 G that the neck was fractured in two cases, with a 4 inch transection of the cervical spine occurring in one instance (66). This was not predicted from dummy data.

Some of the major breakthroughs in our knowledge of acceleration have occurred through accident or through purposeful studies in which the researcher uses himself as a subject. Examples of this are Colonel Stapp's sled ride of 632 mph to demonstrate that a human could survive such forces of windblast and deceleration in an aircraft ejection; Major Beeding's rearward facing deceleration of 83 G, and Lt. Colonel Kittinger's rotation during delayed free-fall from 86,000 feet. Obviously we can not experimentally test restraint systems using a statistically valid sampling of the human population including elderly, infirm, babies and children, obese, etc. But in another sense this is done through epidemiological studies of automobile accidents in investigations conducted by researchers such as Moseley in Massachusetts (52), Huelke and Gikas in Michigan (37) and Nahum and Siegel in California (53). Such work is important to demonstrate the value, or deficiency, of such things as restraint devices and plays an important role in contributing to our knowledge and future design.

Human tolerance to lap belt crash forces has been experimentally studied on the Daisy Track, Swing decelerator, and Bopper, at Holloman Air Force Base. Hasbrook, in 1956, rode the NACA decelerator with a measured seat deceleration of 7 G and "probable" 14 G chest, resulting in bruising and lower abdominal complaints (33). Subjective reactions found by Lewis and Stapp to 15-20 G impacts were complaints of abdominal pain. They concluded that decelerative force exceeding 10 G, at 300 G per sec rate of onset, for .002 seconds duration would result in minimal contusions over the hip region due to lap belt impingement (70, p. 66). At 13 G, with the same time duration and rate of onset, in addition to contusions, strain of abdominal muscles could be expected with accompanying soreness. On one run reported to be at 26 G,

the highest human voluntary impact of that series, using a lap belt only, the subject complained of severe epigastric pain persisting for 30 seconds, and pain in the area of the thoracic vertebra continuing for 48 hours. Seat belt forces in this case were 4290 lbs. Impingement area of the 3 inch nylon lap belt (with standard AF hardware [16 inch length] was 48 sq. inches) and average impingement area force was calculated to be 89.3 psi. Subsequent human tests on the Daisy Track have not exceeded 15 G forward-facing with lap belt only. This is generally considered to be the upper limit of the subjective tolerable impact. A 30-mph barrier crash (equivalent to a head-on crash of 40-60 mph) has been found to impose seat belt loads on anthropomorphic dummies of 3000-6000 pounds. Higher forces have been experimentally measured during animal impacts.

Note that belt forces of 1518-3588 pounds (31.0-74.7 psi belt pressure at .001-.003 seconds duration at 15-23 G on abdomen were found in the Lewis and Stapp tests of volunteers. Only three of these subjects were reported (out of 19) to have received belt bruises in the impingement area, but two others were sore at the lower margin of the rib cage, one for four days, one for two weeks. However, these forces would probably be close to the subjective tolerance limits, since these subjects were all healthy young males. It is important to note that a difference was found in subjective tolerance not only between individuals, but within the same individual on different runs. In similar tests a subjective limit of 9 G was found to be the highest voluntary level in the lateral position (97). In the rearward facing position volunteers have been impacted only while utilizing a full torso harness.

A study of optimum restraint for the U. S. Army resulted in a recommendation of transverse design load factors of 45 G for 0.10 second and 25 G for 0.20 second with harness loads for a minimum of 0.10 second of 4000 lb for shoulder straps and 6000 lb for the lap belt (31). Due to the higher G loadings which are often encountered in the automotive accident, automotive seat belts (lap) are presently designed for greater strength (4-6000 lb) than aircraft, which are presently only required to meet 2000 lb loads in general aviation aircraft.

Many investigators speak of a "submarining" action, in which the individual slides under the belt in deceleration, which is one reason that military restraint systems often use a fifth

crotch belt (31). Submarining may occasionally occur in aircraft, especially to an occupant wearing a loose lap belt and tight shoulder harness. But note that the impact angle may be quite different from the horizontal force incurred in the typical automobile crash. Also, while 50th percentile anthropomorphic dummies may occasionally describe "submarining" kinematics, researchers have yet to document such a situation occurring in actual automotive crashes (53).

VI. Discussion

Review of the epidemiological and clinical studies cited in this paper clearly shows that seat belts do greatly assist the automotive occupant in the prevention of more extensive or fatal injuries in most impact situations as compared to the non-belted occupant. But these studies, reinforced by experimental data, also indicate that effectiveness is dependent upon a number of environmental factors, and that while some seat belt restraint systems offer measurably greater protection to the individual than others, even the "best" system can offer poor protection under some circumstances.

There appears to be relatively universal agreement among researchers as well as clinicians that the *major* usefulness of any seat belt restraint system is in the prevention of ejection from the vehicle during an impact. Indeed, Campbell and Kihlberg in a Cornell Aeronautical Laboratory ACIR study conducted in California in 1963, found *no* substantial benefits from 232 matched pairs of accident occupants, half wearing belts, and half not wearing belts, through preventing or reducing contact with interior vehicle surfaces, beyond ejection control (10).

Other factors can influence injuries as well. For some time, for example, there apparently has been a fundamental disagreement between American and European researchers concerning use of the lap belt (as used extensively in the U. S.) compared with the single diagonal only system (as used more prominently in Europe) and which probably is in 85% of Swedish cars (5).

In the United States, the lap belt is the most commonly used seat belt system, and has been standard equipment for both front and rear seats in all American automobiles since the 1966 models were introduced. Attachment (anchor-

age, or tie-down) is to the floor on both sides of the seat normally allowing a belt angle of 40° to 60° to the horizontal. Correctly mounted and worn, it provides support of the body's sturdiest framework, the pelvic girdle. It has the disadvantage of allowing the head and thorax to swing free in a "jack-knife" motion during impact. The diagonal (or "bandolier") belt, on the other hand, is anchored to the B-post pillar or above the rear door, and extends across the shoulder and chest on the outboard side, diagonally across the flank on the opposite side, where it is anchored to the floor. This provides diagonal vertical support to the torso, from the hip on one side to the shoulder of the opposite side. The major disadvantage, however, is that with no lap belt horizontal support across the anterior pelvic area, there is nothing to prevent the lower torso from swinging forward and rotating out of the belt at impact (unless stopped by striking the instrument panel or other part of the vehicle itself).

In the smaller European car there is much less distance between the occupant and any potential environmental impact surfaces. In this situation, the lap belt, which allows upper torso flexion forward during $-Gx$ impact, is certainly not as effective in preventing or reducing injury in impact as is a system restraining the upper torso. The use of a lap belt only, while generally preventing ejection "can not provide adequate protection to a seated occupant since the upper body components (e.g., head) are free to move during abrupt decelerations and strike surrounding structures" (93).

However, we must caution those advocating the use of the single diagonal belt only (with no lap belt) as an adequate seat belt system. While the number of experimental tests that we have run to date on primates is insufficient—as presented in preliminary form in this paper—to make valid conclusions, the results to date do indicate strongly that this can be a highly dangerous device. In some 47 experimental tests a number of environmental variables have been explored. In tests utilizing the same size primate subject with identical deceleration patterns, direction of force, body orientation, time duration and rate of onset of impact, seat belt tension, and seat configuration, by direct comparison even the lap belt, purposely incorrectly placed loose and high on the abdomen, resulted in less trauma to the subject from impact alone than that occurring with the diagonal belt alone. Our

201

work so far strongly supports the opinion of medical consultants to *Consumer's Reports* in a comparison of various seat belt systems, who warned as early as 1962, "In a severe front-end crash, CU's tests indicated, this strap might cause critical injuries to internal organs (or the neck, when the wearer slides down out of the belt). Even a lap strap alone is preferable, since at least it puts the pressure on the well-protected pelvic area" (3, P. 485).

This also is supported by Williams et al, who found that the shoulder belt "can produce a more serious injury than the lap belt" (89). Although about 80% of the 712 front seat belted car occupants injured in a South Sweden study were wearing the diagonal belt, the type of belt used was not considered in an analysis of the data (5). Significantly, of 60 injuries noted (not defined as to whether related to the belt) 44 injuries occurred to occupants wearing the diagonal (5).

Lindgren has found cases of multiple fractures of the ribs, fractured clavicles, sternum, a ruptured liver, and one case of rupture of the left atrium of the heart attributed to the diagonal type of belt. He also reported two of three fatalities in a study of 382 accidents comparing injuries with different belt systems used. Lindgren raises the question, in reference to side impacts occurring to drivers wearing diagonal belts, "if the belt may not accentuate the violence sustained by the driver's pelvis when it is thrown against the door during deceleration" (44).

There have been unsubstantiated reports of occupants being decapitated by diagonal belts in side impacts. However any such cases are probably a result of other artifacts, not the belt itself. Lindgren, for example, reports one such case which appeared at first to have been due to the belt, but which was later determined to be due to the driver's head being scissored by the door (44).

In an earlier study by Brunius and Lindgren of 210 accidents to car occupants while wearing belts, the pressure of the belt was considered not to have caused any internal injuries (9). Hanson and Rasmussen found one case of a ruptured spleen attributed to a diagonal belt (32).

It is significant that the warning "This shoulder strap is not to be used without a lap belt" is printed in the Owner's Manual or on the labels of standard 3-point (type II) restraints in U. S. production automobiles. To our knowledge, our experimental tests with primates, still incomplete, are the first experiments involving a living

subject to be conducted with the diagonal belt system only.

In a study conducted last year of 900 Dutch accidents, Bastiaanse and Bouwman compared the effectiveness of hip (lap), 3-point, and diagonal restraint systems. Although they reported twice as much head injury for lap-belt users as for users of other types, they found *three times* as many chest and leg injuries for diagonal and 3-point users as for lap-belt users (6).

Backstrom, in analyzing 712 front seat belted occupants in accidents in Sweden noted that "chest injuries were relatively common among car occupants," occurring in 252 cases (14%) (which he attributed to the steering wheel) (5).

Fletcher and Bragdon (1967) report an oblique fracture of the sternum received by a 33-year-old physician, striking a tree at about 35 mph in a small Swedish car while wearing a diagonal belt. They note that looseness of the belt permitted several inches of forward movement of the thorax, but prevented contact with the steering assembly. They conclude "this type of belt cannot guarantee safety" (21).

One of the earliest analyses of automotive seat belt injuries was conducted by Brunius and Lindgren (9) of 210 accidents between 1957–1960 in Sweden in which belts were worn. With the exception of one belt breaking, one individual slipping out of his belt and being thrown from the car, and a third case in which the belt was too loose, they reported no internal injuries or aggravation due to the belt (3-point type). Lister and Milson in England obtained data on 600 accidents in which 837 belted front-seat occupants were involved. They compared injuries occurring with four types of belts—full harness, lap and diagonal pillar fitting (3-point), lap and diagonal floor fitting (3-point), and diagonal only—finding an overall reduction in expected injuries, in comparison with accidents in which belts were not worn (45). In Australia Birrell (1964) made a similar study (7).

Injury patterns typical of accidents in which the wearer was using a lap belt are shown in Figure 3. Note the somewhat different pattern and location of injuries when the wearer is using a diagonal belt only, as shown in Figure 4.

Injury attributable to the 3-point (type II) restraint system has been less frequently reported. Fisher in 1965 described the first case of a splenic rupture from use of a 3-point combination lap and diagonal belt. Ironically, the impact forces involved were unusually small, a Volks-
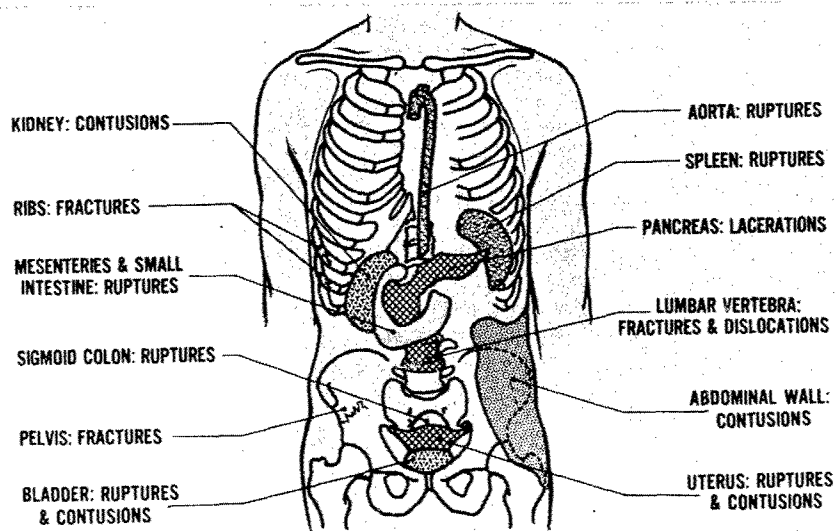
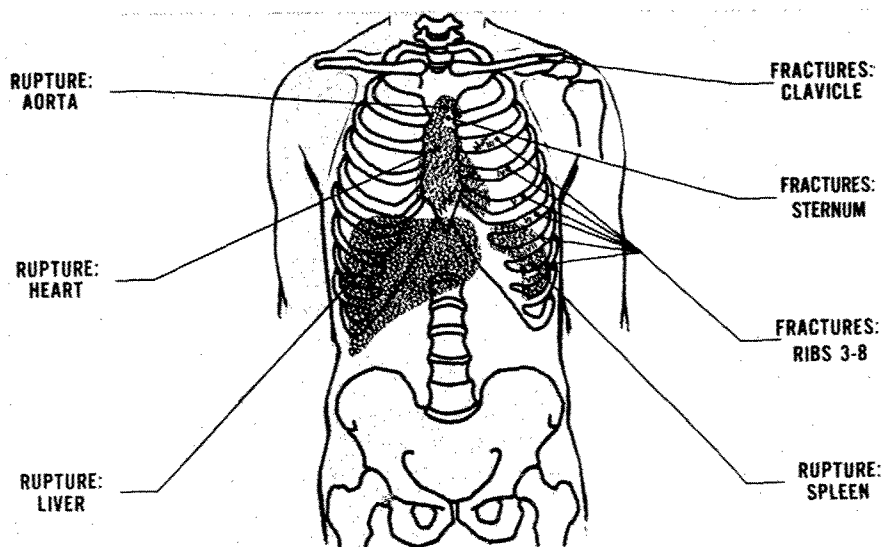Figure 3.   Observed injury patterns in lap belt wearers.

Figure 4.   Observed injury patterns in diagonal belt wearers (without lap belt).

wagen striking a Renault broadside at 5-10 mph from a full stop. Both the 42-year-old woman driver and the 67-year-old woman passenger were wearing snugly fitted 3-point restraints. The driver received a fractured sternum; the passenger fractures of the left fifth, sixth, seventh, eighth and ninth ribs, and a severely lacerated spleen. Since this woman had been taking Coumadin® daily for two years prior to this accident for anticoagulation, the hemorrhaging of the spleen required unusual treatment (20). In another case, Fletcher and Bragdon reported fractures of the left 6-9th ribs and rupture of the spleen (21).

A second case, involving a hyper-extension, hyper-flexion cervical injury, was attributed by Ebbetts to a 3-point belt. In his opinion trauma occurred "in a low-velocity impact in which there was little danger of serious injury to the patient had she not worn a seat belt. Conversely, it was an injury which was definitely aggravated by the use of a seat belt" (16).

Young, in a recent dynamic comparison of dummy impacts conducted by the Federal Aviation Agency involving eight different restraint systems, found a significant difference in effectiveness between a lap belt and 3-point or full-torso restraint in body kinematics. He concluded that the double parallel shoulder harness system provided better restraint function than the other types, including the three-point belt "for at least two reasons: (a) the distribution of applied loads to two belts is greater than the same loads applied to a single belt, therefore less belt stretch results in a greater restriction of forward movement, and (b) certain combinations of omnidirectional forces have a tendency to cause a body torquing action with a single diagonal [sic, 3-point] restraint that may result in a less efficient restraint function." He also found that the relative position of the seat belt tie-down, which ultimately establishes the seat-belt angle, is a significant factor; too forward a tie-down location can seriously compromise an otherwise good restraint system. Figure 5, adapted from Young, shows in body kinematics the relative restraint provided dummies wearing three different systems (identical impact patterns).

Similarly, in a 3-point (type II) restraint system which is used in many 1967 automobiles, and will be required for most 1968 models, the location of the upper belt anchorage can be critical in influencing effectiveness of the system. For example, if the upper anchorage is too far forward, relative to the seated occupant, the belt angle will be such that it is too low on the shoul-
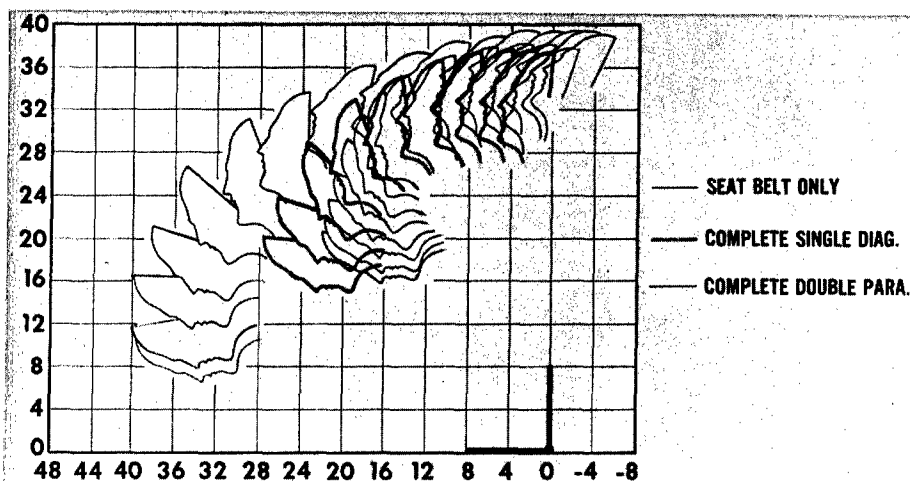

Figure 5. *A comparison of body kinematics of a 95th percentile dummy restrained by three different restraint systems while decelerated at approximately 41 ft/sec.*

der, and the individual cannot only flex over it and slip out, but will be torqued forward and sidewards during the deceleration, which may be particularly injurious. On the other hand, if the anchorage location is too far to the rear, relative to the seated occupant's position, the diagonal belt will impinge upon the neck, causing discomfort even during normal driving. Such a situation might, by creating pressures upon the blood vessels of the neck and particularly the carotid artery, as well as pressing upon nerves, have a subtle but disastrous effect. In an impact or rapid deceleration severe neck injury could occur. This presents a dilemma to the package designer who must consider seat positions for a wide range of physiques, using limited attachment points, as well as what to do with up to 27 separate belts in one vehicle. Improper positioning may also affect occupant acceptance and future use of the 3-point system if, upon first experience, it is not comfortable, rubs against the neck, or will not allow proper freedom to reach controls.

Other than racing car accidents and a statistical study by Lister and Milsom (45), no injuries to automobile occupants wearing double shoulder harnesses during an accident have been described as yet.

Nevertheless, based on numerous studies by previous investigators and experience in military aircraft, the most effective belt system of the four belt systems considered here is a modification of the full shoulder harness type such as is installed in all commercial air transport flight deck pilot positions to be worn during landing and takeoff phases. Such a system, equipped with an inertia reel retractor device, offers the compatible combination of comfort, since the shoulder harness reel allows free range of motion until the harness is locked during deceleration, plus better protection to the occupant than the 3-point, lap, or diagonal systems. However, even this system has installation variations which can be undesirable in use.

Few belts of the double torso type are as yet in use in U. S. automotive vehicles, although they have long been used in aircraft. The Shelby-American (Cobra) GT 350 and GT 500 cars, for example, have utilized since late 1966 a variation of the double shoulder restraint harness. This system, resembling an inverted Y, features an inertia reel retractor, allowing full body motion to reach controls, but locking at a predetermined .3 to .5 G activation. As yet there have been no reported accidents or injuries with this

system. This is similar in appearance to a Ford harness presently undergoing biomechanical evaluation. The Indiana State Police have been evaluating a 3-point harness with an Advanced Safety Devices emergency locking retractor. Police officers involved in several accidents to date while wearing this system have apparently avoided serious injury. However, it should be noted that there is no mass production experience (for automobiles) with inertia reels adjusted to lower 0.3 to 0.5 G activation (aircraft reels are adjusted to about 2.0 G). Many tests to date have not demonstrated adequate reliability of the reel.

In the study by Listor and Milsom of the Road Research Laboratory in England (45), of 355 individuals wearing full harnesses in accidents, 244 received no injury. Of the 111 receiving some injury, 36 were to the head, 6 to the neck, 17 to the thorax including belt bruising, 5 to the thigh, and the balance of 51 to the lower extremities. However, information concerning correlation with type of accident and impact conditions was not provided. (A similar study conducted in the United States, where vehicles are larger and intruding environments offer more distance between the occupant and environment during an impact, might demonstrate even better protective results). Deaths to occupants were not reported; however, this study indicates that the full body restraint provides good protection in even severe accidents, compared to other types worn. The authors conclude that this type of harness, in comparison to the other types studied, provided more restraint to the upper torso, resulting in fewer head and neck injuries but more chest injuries, including "bruising caused by the seat belt assembly."

Other types of restraint devices, such as air bag systems, will be discussed in other papers of this symposium. Perhaps the ultimate in full body protection is the isovolumetric complete body encapsulation developed by Lombard (46) for space use, and in which an occupant might survive 200 G impact forces. Such a system, however, would probably not be popular among housewives or teenagers on dates.

Legal Aspects. To provide seat belts is not enough. For seat belts to be of any use, people must be effectively convinced to wear them to be of any use, and, as injury data is beginning to demonstrate, they must be worn correctly. As early motivation for airplane drivers may have been simply to keep from falling out of the air-

205

craft, so also, perhaps, a new motivation is occurring for the motorist.

It is of interest to note that recent court decisions on injuries have ruled that the plaintiff's failure to wear a safety harness—with which the car was equipped at the time of the accident—constituted contributory negligence. McRoberts (1965) reports a case in which the jury reduced the award the plaintiff would have received by 10% because of her negligence in *not* wearing the belt provided (49). In a more recent Texas case the plaintiff's recovery of damages was reduced by 95%. The two legal principles applying in the latter case are that "the plaintiff has a duty to use reasonable care for his own safety," and that "where plaintiff's prior conduct does not bring about the impact or accident but has aggravated the ensuing damages, plaintiff's recovery is reduced to the extent that his damages have been aggravated by his own conduct" (41). While this may seem reasonable, the opposite may now apparently be true. Cases occur in which particular injuries are attributed to the wearing of a seat belt, as, for example, that which was reported recently in a Connecticut newspaper (which must be viewed as speculative by the researcher until discreet environmental data in each instance are obtained to define causes of injury). As has been pointed out in this paper, there are numerous factors which can play a part in contributing to a seat-belt injury, but these may not always be due to the characteristics of the belt itself, but rather to such factors as improper wearing.

VII. Summary

Although the seat belt restraint system has been demonstrated to provide effective reduction of injuries and fatalities in automobile accidents by preventing ejection, with increasing usage of belts by automotive occupants a pattern of injuries directly attributable to impingement on the belt itself is becoming evident. This paper has attempted to bring together the clinical evidence concerning seat belt injuries, discuss gross biomechanical mechanisms of trauma, and evaluate the potential of four principal types of restraint systems to produce injuries. New experimental research findings by the authors are presented comparing the lap belt, diagonal, 3-point, and double torso restraint systems in experimental primate impacts utilizing the 6571st Aeromedical Research Laboratory's Daisy Decelerator, as well as discussion of findings related to the

effect of the lap belt in impact upon the pregnant female and fetus. It is concluded that the double shoulder harness probably offers the greatest protection of the systems compared, while the single diagonal belt (without lap belt) may be the most dangerous type in certain impact situations. However, to allow freedom of control reach, a reliable inertia reel is also necessary for an effective system. It is emphasized that the seat belt, properly installed *and worn*, offers the single best protection for the automotive occupant during an impact.

References

1 Aiken, D. W., 1963 "Intestinal Perforation and Facial Fractures in an Automobile Accident Victim Wearing a Seat Belt" *J. Louisiana State Med. Soc.* 115(7):235–236.

2 Aldman, B., 1962 "Biodynamic Studies on Impact Protection" *Acta Physiologica Scand.* Stockholm 56 (Suppl. 192)

3 Anon. 1962 Auto Seat Harnesses, *Consumer Reports*, October. pp. 484–487.

4 Anon. 1967, "Nearly Two-Thirds of Drivers in Survey Do Not Use Seat Belts" *Traffic Safety* 67(4):42

5 Backstrom, C., 1963 Traffic Injuries in South Sweden with Special Reference to Medico-Legal Autopsies of Car Occupants and Value of Safety Belts. *Acta Chirurgica Scandinavica,* Suppl. 308.

6 Bastiaanse, J. C. and Bouwman, A. A., 1966 Statistical Study. Effectiveness (of) Seatbelts. Rapport. RA1-TNO, Instituut Voor WegtransportMiddelen. Netherlands.

7 Birrell, J. H., 1964 "Safety Belts for Motor Vehicles in Victoria" *Med. J. Australia* 1:67

8 Bourke, G. J., 1965 "The Efficiency of Car Safety Belts" *J. Irish Med. Assoc.* 57:110–117.

9 Brunius, U., and Lindgren, S., 1961 "The Effectiveness of Safety Belts. An Analysis of 210 Belt Cases" *Nord. Med.* 66(44):1500–1503.

10 Campbell, B. J. and Kihlberg, J. K., 1964 "Seat Belt Effectiveness in the Non-Ejection Situation" *Proceedings, Seventh Stapp Car Crash Conference,* C. C. Thomas.

11 Campbell, H. E., 1964a. "The Automotive Seat Belt and Abdominal Injury" *Surgery* 119:591–592.

12 Cocke, W. M., Jr., and Meyer, K. K., 1963 "Splenic Rupture Due to Improper Placement of Automotive Safety Belt" *J. Amer. Med. Assoc.* 183(8):693

13 Crosby, W. M., Snyder, R. G., Hanson, P., Snow, C. C.: 1967 "Impact Injuries in the Pregnant Female: I. Experimental Studies," in preparation for presentation Central Association of Gynecologists and Obstetricians Annual Meeting. Detroit.

14 DeHaven, H., Tourin, B., Macri, S., 1953 "Aircraft Safety Belts: Their Injury Effect on the Human Body" Crash Injury Research of Cornell University Medical College.

15 DuBois, E. F., Safety Belts are Not Dangerous. *Brit. Med. J.* 2:605, 1952

16 Ebbetts, J., 1962 "Seat Belts and Cervical Spondylosis" *Practitioner* 188:802.

17 Elias, M., 1950 "Rupture of Pregnant Uterus by External Violence," *Lancet* 2:253–254, August.

18 Engberg, A., 1961 "Injuries Caused by Safety Belts. A Contribution to the Discussion with Reference to an Unusual Case" *Svensk. Lakartidn.* 55:884–886.

19 Fish, J., and Wright, R. H., 1965 "The Seat Belt Syndrome—Does It Exist?" *J. Trauma* 5(6):746–750.

20 Fisher, P., 1965 "Injury Produced by Seat Belts: Report of 2 Cases" *J. Occupational Medicine* 7:211–212.

21 Fletcher, B. D. and Bragdon, B. G., "Seat-Belt Fractures of the Spine and Sternum", *JAMA* 200(2):177–178 April 10, 1967.

22 Frazier, R. G., 1961 "Effectiveness of Seat Belts in Preventing Motor Vehicle Injuries" *New England J. Med.* 264:1254–1256.

23 Fredericks, R. H., 1961 "Progress in Safe Vehicle Design" *The Fifth Stapp Automotive Crash and Field Demonstration Conference,* The University of Minnesota, 14–16 September, pp. 225–240.

24 Fredericks, R. H., 1965 "Barrier Collision Investigation of Harness Restraining Systems" *Proceedings, Seventh Stapp Car Crash Conference.* Springfield, Ill.: C. C. Thomas.

25 Garrett, J. W., 1963 "A Study of Seat Belts in Wisconsin Automobile Accidents" Cornell Aeronautical Laboratory, Inc. Rept. No. VJ-1823-R3. Sept.

26 Garrett, J. W. and Braunstein, P. W., 1962 "The Seat Belt Syndrome" *J. Trauma* 2:220–238.

27 Gerritsen, R., Frobese, A. S., Pezzi, P. J., 1966 "Unusual Abdominal Injuries Due to Seat Belts" *J. of the Albert Einsteain Medical Center* 14(1):63–66.

28 Gissane, W., Bull, J., 1964 "A Study of Motor-Way Fatalities" *Brit. Med. J.* 1:75.

29 Gogler, E., 1965 *Road Accidents,* Geigy, Basle, Switzerland ("Unfallopfer im Strassenverkehr" Series Chirurgica Geigy No. 5 (1962.)

30 Grime, G., 1963 "Seat Harness. Effect of a Harness on the Movement of the Occupant of a Car During a Head-on Collision" *Auto Engr.* 53:12.

31 Haley, J. L., 1962, Personnel Restraint Systems Study, Basic Concepts. AvCIR 62–12. Dec. U. S. Army Transportation Research Command. Fort Eustis, Virginia.

32 Hansen, O. M., and Rasmussen, P. S., 1963 "Traffic Accident with a Spleen Injury Associated with the Use of a Safety Belt" *Ugeskr. Laeg.* 125:771–773.

33 Hasbrook, A. H., 1956 Design of Passenger "Tie-Down". "Some Factors for Consideration in the Crash-Survival Design of Passenger Seats in Transport Aircraft" Report AvCIR 44-9-66. Aviation Crash Injury Research of Cornell University, Flushing, N.Y.

34 Hasbrook, A. H., 1959, "Severity of Injury in Light Plane Accidents. A Study of Injury Rate, Aircraft Damage, Aircraft Severity, Impact Angle, and Impact Speed Involving 1596 Persons in 913 Light Plane Accidents". Aviation Crash Injury Research, Flight Safety Foundation, Report AvCIR 6-SS-105 (July).

35 Herbert, D. D., 1964, *Med. J. Austr.* 1:61

36 Howland, W. J., Curry, J. L. and Buffington, C. B., 1965 "Fulcrum Fractures of the Lumbar Spine" *J. Amer. Med. Assoc.* 193 (3):240–241.

37 Huelke, D. F., and Gikas, P. W., 1966 "Ejection—The Leading Cause of Death in Automobile Accidents" *Conference Proc., 10th Stapp Car Crash Conference.* Holloman AFB, 8–9 November, pp. 156–181.

38 Hurwitt, E. S., and Silver, C. E., 1965 "A Ventral Hernia Following an Automotive Crash" *J. Amer. Med. Assoc.* 194(7):829–831.

39 Jenks, A. C., 1966 Personal communication.

40 Kulowski, J. and Rost, W. B., 1956 "Intra-Abdominal Injury from Safety Belt in Auto Accident. Report of a Case" *Arch. Surg.* 73:970–971.

41 Lawrence, J. M., 1966 "Seat Belt Liability: Texas" *Defense Memo* 7(7):52–53.

42 Lewis, S. T. and Stapp, J. P., 1958 "Human Tolerance of Aircraft Seat Belt Restraint" *J. Aviation Med.* 29:187–196.

43 Life, J. S., Pince, B. W., Brian, M., Heberlein, P. J. and Gesink, J. W.: "Comparative Responses of Live-Anesthetized and Dead Embalmed Monkeys Exposed to Impact Stress. Phase I" Space/Defense TR 66-107 16 Sept. 1966. (Submitted to *Science* as "Comparative Pathology of Live and Embalmed Monkeys Exposed to Impact")

44 Lindgren, S. and Warg, E., 1962 "Seat Belts and Accident Prevention" *Practitioner* 188:467–473.

45 Lister, R. D. and Milson, B. M., 1963 "Car Seat Belts: An Analysis of the Injuries Sustained by Car Occupants" *Practitioner* 191:332–340.

46 Lombard, C. F. and Advani, S. H., 1966 "Impact Protection by Isovolumetric Containment of the Torso" *Conf. Proc. 10th Stapp Car Crash Conference.* Holloman AFB, New Mexico.

47 MacVean, S. S., 1966 Seat Belt Usage and Vehicle Occupancy Data. Ford Motor Co. Technical Memo, PRM 66-26. 9 August.

48 McHenry, R. R., 1965 "Analysis of the Dynamics of Automobile Passenger-Restraint Systems" *The Seventh Stapp Car Crash Conference Proceedings,* C. C. Thomas.

49 McRoberts, J. W., 1965 "Seat Belt Injuries and Legal Aspects" *Industrial Med. & Surg.* 34:866–869.

50 Michelsen, I., Aldman, B., Tourin, B., and Mitchell, J., 1964 "Dynamic Tests of Restraining Devices for Automobile Passengers" *Public Health Reports* 79:125.

51 Moreland, J. D., 1962, "Safety Belts in Motor Cars, an Assessment of Their Effectiveness" *Ann. Occup. Hyg.* 5:95.

52 Moseley, A., 1963 "Research on Fatal Highway Collisions Papers 1962–1963" Harvard Medical School.

53 Nahum, A., and Siegel, A., 1967 Personal communication.

54 Patrick, L. M. and Daniel, R. P.: "Comparison of Standard and Experimental Windshields" L. M. Patrick, ed., *Eighth Stapp Car Crash and Field Demonstration Conference,* 1964. (Detroit, Mich.: Wayne State University Press, 1966) pp. 147–166.

55 Patrick, L. M., Mertz, H. J. and Kroell, C. K., 1966 "Impact Dynamics of Unrestrained, Lap Belted, and Lap and Diagonal Chest Belted Vehicle Occupants" *Conf. Proc. 10th Stapp Car Crash Conf.,* Holloman AFB, New Mexico, 8–9 November, pp. 22–53.

56 Quinn, F. B., Jr., 1962 "Are Seat Belts Enough?" *Gen. Pract.* 26:101

57   Raney, E. H., 1966 "Fetal Death to Non-Penetrating Trauma of the Gravid Uterus." Presented at the District VI Meeting of the American College of Obstetricians and Gynecologists, Omaha, Nebraska. 30 September.

58   Rubovits, F. E., 1964 "Traumatic Rupture of the Pregnant Uterus from 'Seat Belt' Injury" *Amer. J. Obstetrics and Gynecology* 90(6):828–829.

59   Schulman, M., 1965 "Metropolitan Toronto Coroner's Office Statistical Report. 1965.

60   Schwimmer, S. and Wolf, R. A., 1962 "Leading Causes of Injury in Automobile Accidents" Automotive Crash Injury Research of Cornell University, Ithaca, New York.

61   Severy, D. M., 1950 "Photographic Instrumentation for Collision Injury Research" *J. Soc. Motion Picture and Television Engineers* 67(2):69–77.

62   Severy, D. M., 1966 "Human Simulation Techniques by Collision Researchers" *8th Stapp Car Crash and Field Demonstration Conference.* Wayne State University Press. Detroit

63   Smith, W. S., Kaufer, Herbert, 1967 "A New Pattern of Spine Injuries Associated with Lap Type Seat Belts," *U of M Medical Center Journal,* Vol. 33, May–June.

64   Snow, C. C., Snyder, R. G., Price, G. T., Shires, T. K. and Parry, W. L. 1967 "Trauma to the Urinary System Caused by Abrupt Deceleration" In preparation for presentation, Scientific Session on Urology, Annual Meeting American Medical Association, October.

65   Snyder, R. G., 1966 "Civil Pilot Accident Experience with High Performance Single Engine Light Executive Type Aircraft" Paper presented at International Air Safety Seminar, Flight Safety Seminar, Madrid, Spain. November.

66   Snyder, R. G., Crosby, W., Hanson, P., Snow, C. C., Chandler, R. and Fineg, J., 1966 "Impact Injury to the Pregnant Female and Fetus in Lap Belt Restraint" Presented at 10th Stapp Car Crash Conference, Holloman AFB, New Mexico (in press) 8 November.

67   Snyder, R. G., Snow, C. C., Young, J. W., Price, G. T. and Hanson, P. 1967 Experimental Comparison of Trauma in Lateral (-G$_y$), Rearward Facing (-G$_x$) and Forward Facing (-G$_x$) Body Orientations When Restrained by Lap Belt Only. *Aerospace Med.* (in press).

68   Sonntag, R. W. Jr., 1967 "Intracranial Pressure in *Macaca Speciosa* During Controlled Abrupt Deceleration" In, Aerospace Medical Association, *Preprints of Scientific Program,* 1967 Annual Meeting. Washington, D. C. pp. 162–163.

69   Stapp, J. P., 1955 "Tolerance to Abrupt Deceleration" In *Collected Papers on Aviation Medicine.* Butterworths Sci. Publ., London. AGARDograph No. 6, pp. 122–139.

70   Stapp, J. P., and Lewis, S. T., 1956 "Criteria for Crash Protection in Armed Forces Ground Vehicles" HADC TN. Holloman AFB, New Mexico.

71   Stapp, J. P., 1957 "Human Tolerance to Deceleration" *Amer. J. Surg.* 93(4):734–740.

72   Stapp, J. P., 1957 Hearings before a Subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, 85th Congress, First Session, on Crashworthiness of Automobile Seat Belts. #97108, U. S. Government Printing Office, 5–8 August.

73   Stapp, J. P. and Lewis, S. T., 1957 "Human Factors of Crash Protection in Automobiles" *SAE Transactions* 65:488–492.

74   Stapp, J. P. and Lewis, S. T., 1957 "Experiments Conducted on a Swing Device for Determining Human Tolerance to Lap Belt Type Decelerations" AFMDC TN-57-1. Holloman AFB, New Mexico.

75   Stapp, J. P. and Enfield, D. L., 1958 "Lap Belts Need Sound Design" *SAE Journal* 66(9):30–31, Part II.

76   Stapp, J. P., 1958 "Crash Injury Prevention Part I" *Cincinnati J. Med.* 39(1):1–5.

77   Stapp J. P., et al 1958 "Human Tolerance to Aircraft Seat Belt Restraint" *J. Aviation Med.* 29(3):187–196.

78   Stapp, J. P., 1962 "After Seat Belts . . . What?" In Cragun, M. K. (ed.) The Fifth Stapp Automotive Crash and Field Demonstration, pp. 259–263.

79 Stapp, J. P., 1966 "Part II. Effects of Seat Belts: Man" *Environmental Biology*, p. 229. Federation of American Societies for Experimental Biology. Bethseda.

80 Swearingen, J. J. and Morrow, D. J., 1956 "Motion of the Head and Trunk Allowed by Safety Belt Restraint During Impact" Civil Aeronautics Medical Research Laboratory, Columbus.

81 Swearingen, J. J., Hasbrook, A. H., Snyder, R. G. and McFadden, E. B. 1963 "Kinematic Behavior of the Human Body During Deceleration" Aerospace Medicine 32(2):249 (Abstract). Civil Aeromedical Research Institute Report 62-13, Okla. City.

82 Taylor, E. R., Chandler, R. F., Rhein, L. W., Edwards, R. H. and Carter, V. L., 1963 "The Effects of Severe Impact on Bears" Presented 34th Annual Meeting Aerospace Medical Association, Los Angeles, 29 April-2 May.

83 Teare, D., 1951 "Post-Mortem Examination on Air Crash Victims" *Brit. Med. J.* 2:707-708.

84 Tolins, S. H., 1964 "An Unusual Injury Due to the Seat Belt" J. Trauma 4:397-399.

85 Tourin, B., *Public Health Reports*, 73:381. Washington, D. C.

86 Tourin, B. and Garrett, J., 1960 "Safety Belt Effectiveness in Rural California Automotive Accidents" Automotive Crash Research of Cornell University.

87 von Bahr, V. and Eriksson, E., 1961 "Injuries Caused by Safety Belts" *Svensk. Lakartidn.* 58:141-143.

88 von Gierke, H. E., 1964 "Biodynamic Response of the Human Body" *Appl. Mech. Rev.* 17(2):951-958. Dec.

89 Williams, J. S., Lies, B. A., and Hale, H. W., 1966 "Intra-Abdominal Injury from Seat Belts." *J. Trauma* 6:303-315.

90 Williams, R. D. and Sargent, F. T., 1963 "The Mechanism of Intestinal Injury in Trauma" *J. Trauma* 3:288-294.

91 Wolf, R. A., "The Discovery and Control of Ejection in Automobile Accidents" *J. Amer. Med. Assoc.* 180:114 -

92 Woodhull, R. B., 1942 "Traumatic Rupture of Pregnant Uterus Resulting from Automobile Accident" *Surgery* 12:615-620 (Oct.)

93 Young, J. W., 1966 Recommendations for Restraint Installation in General Aviation Aircraft. OAM Report 66-33. Federal Aviation Agency.

94 Young, J. W., 1967 "A Functional Comparison of Basic Restraint Systems" OAM Report (in press) Federal Aviation Agency.

95 Young, J. W., Clauser, C. and McConville, J. T., 1967. Paper in preparation.

96 Young, J. W. and Wilson, D., 1967. Paper in preparation.

97 Zaborowski, A. V., Rothstein, J. D. and Brown, W. K., "Investigations in Human Tolerance to Lateral Impact." Presented 36th Annual Meeting Aerospace Medical Association, April 26-29, New York City, 1965. Abstract: *Aerospace Medicine* 36(2):168-169. Unpublished.